National Aeronautics and
Space Administration

Space Technology & the Moon to Mars Strategy

NAC TI&E Committee (03 Aug 22)

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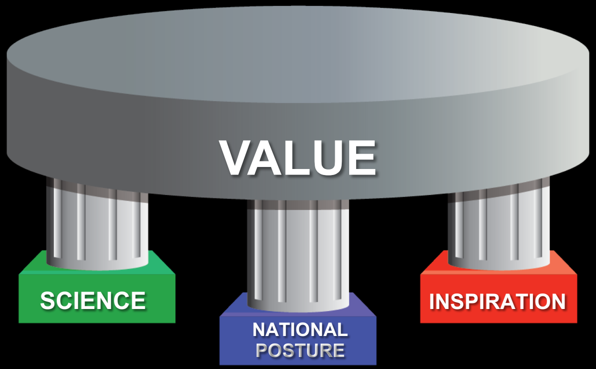
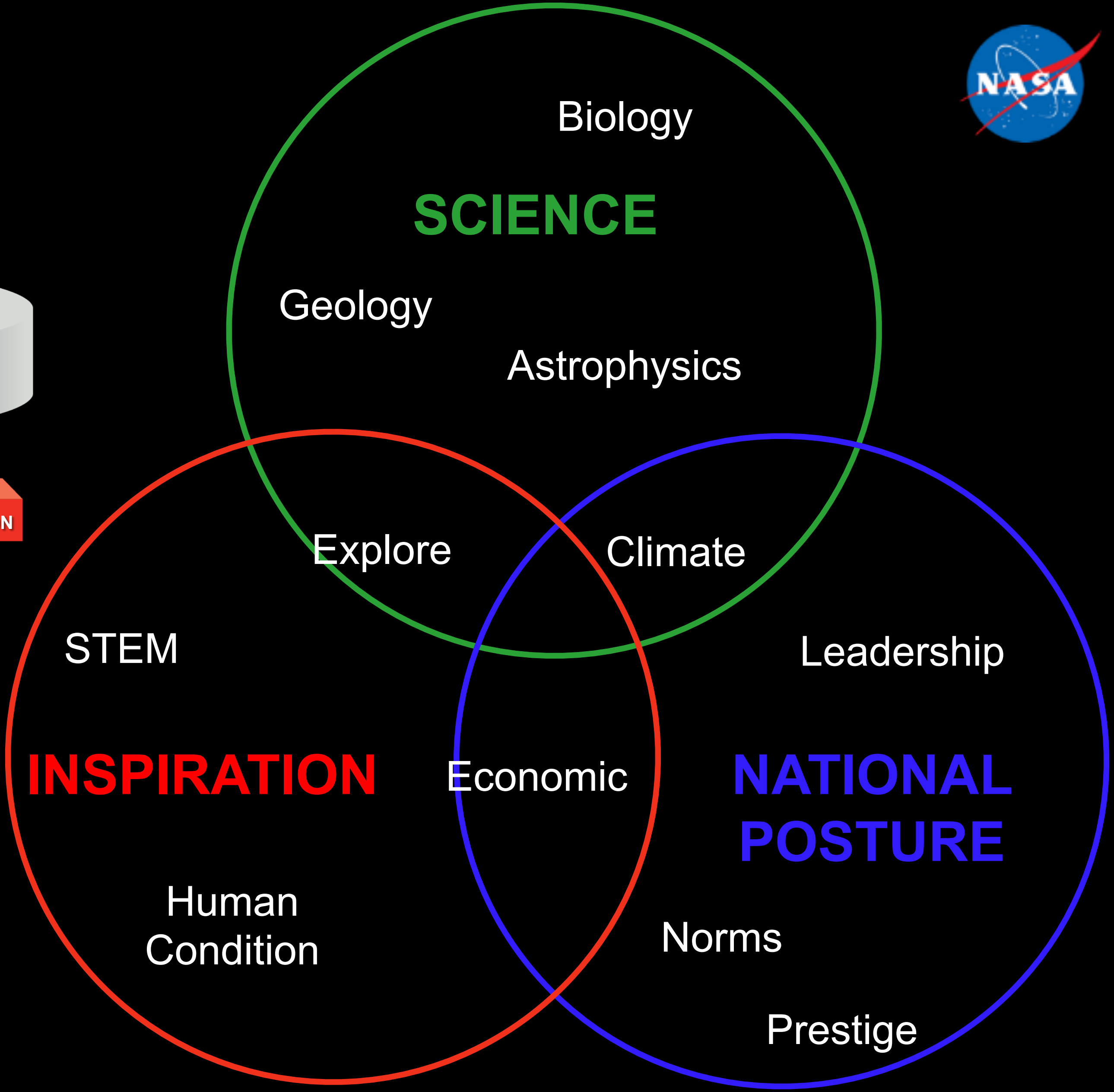
Moon to Mars (M2M) Strategy Brief

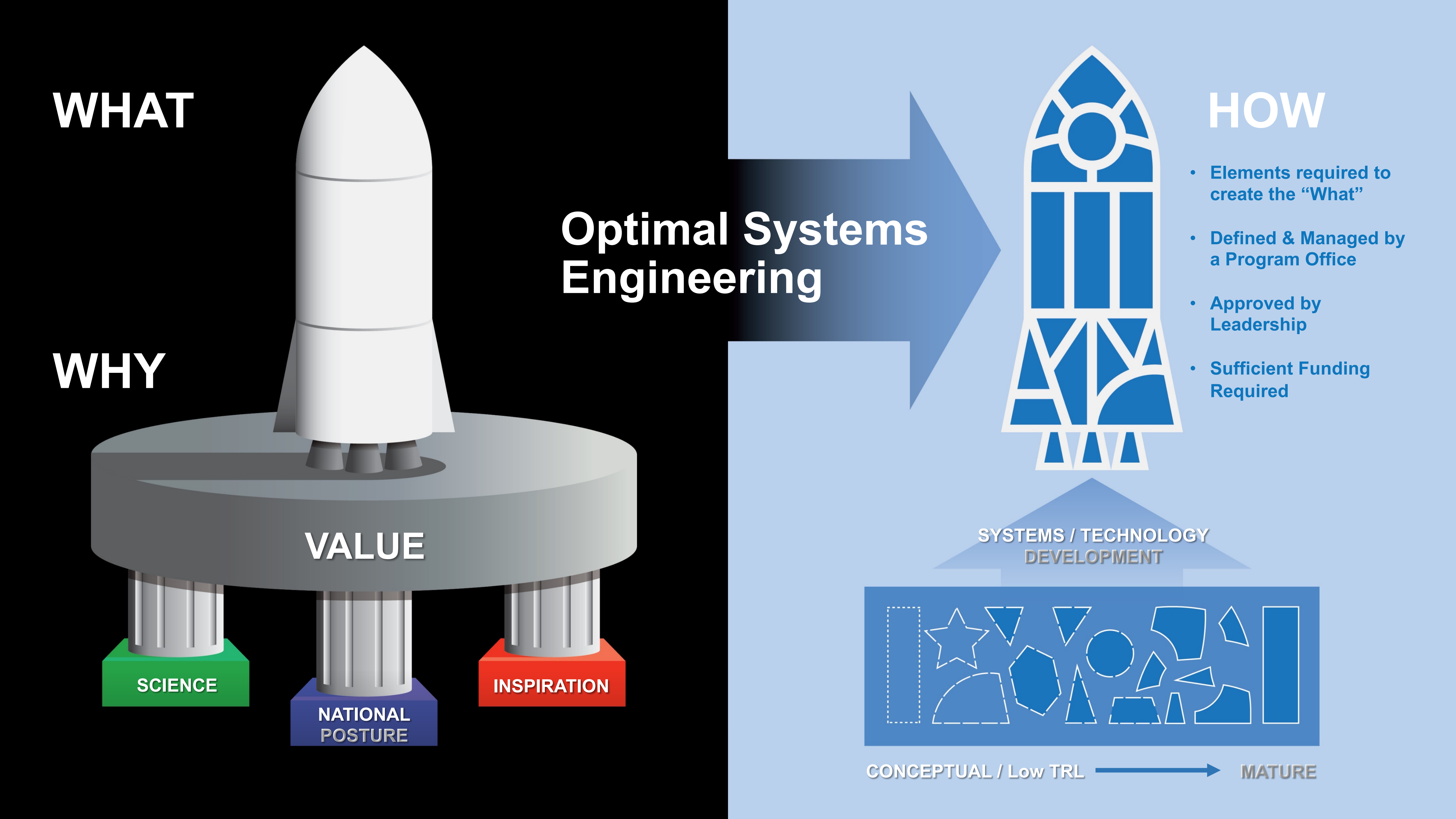
- **Methodology, Observations, & Considerations**
- Framework Objectives
- Gap Analysis & Way Ahead
- STMD’s role

Why Go?

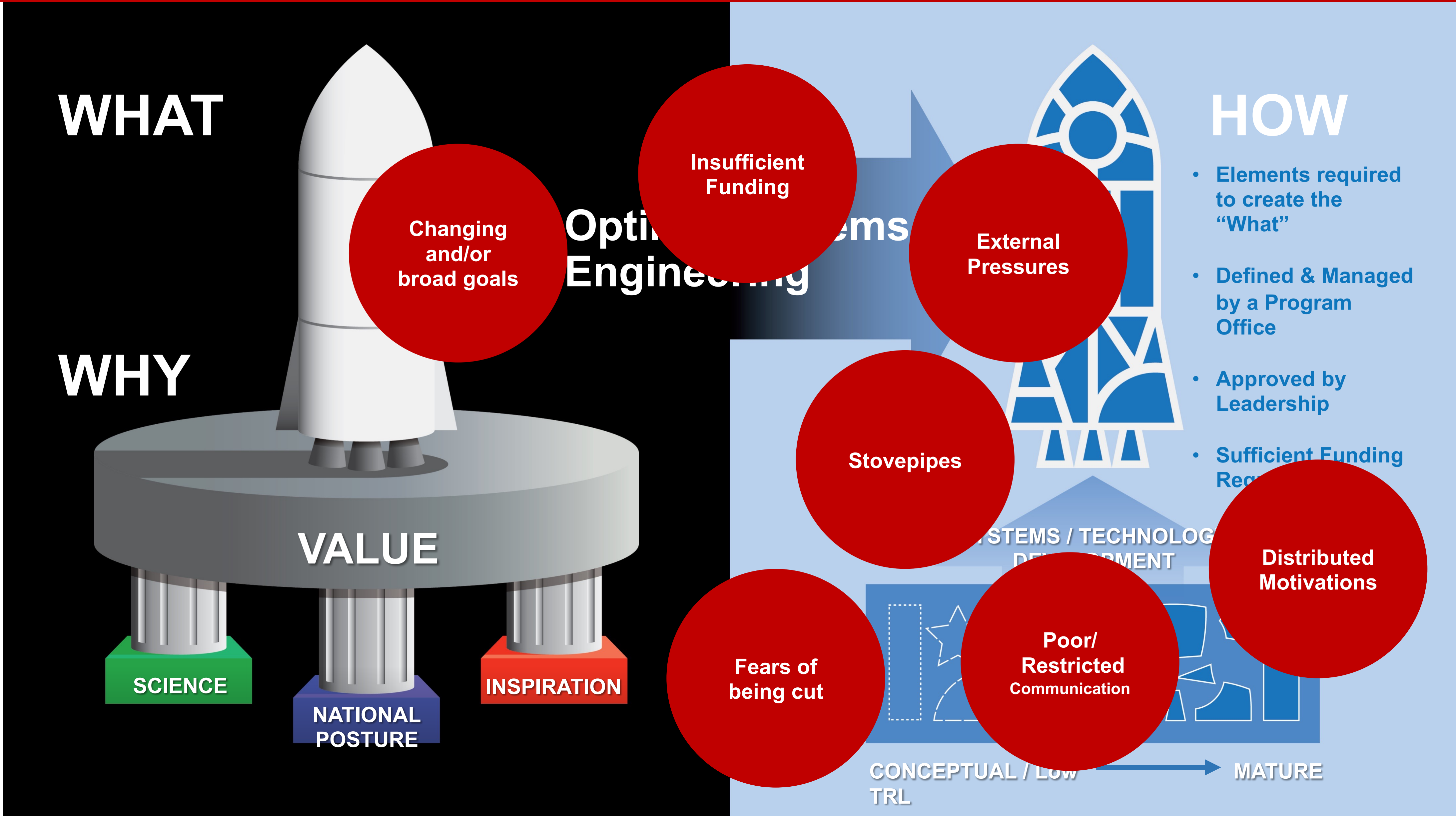
Benefit to Citizens






WHAT
WHY
Optimal Systems Engineering
HOW
• Elements required to create the "What"
• Defined & Managed by a Program Office
• Approved by Leadership
• Sufficient Funding Required
VALUE
SCIENCE
NATIONAL POSTURE
INSPIRATION
SYSTEMS / TECHNOLOGY DEVELOPMENT
CONCEPTUAL / Low TRL
MATURE

Hindrances to Effective Systems Engineering



Broader Historical Context

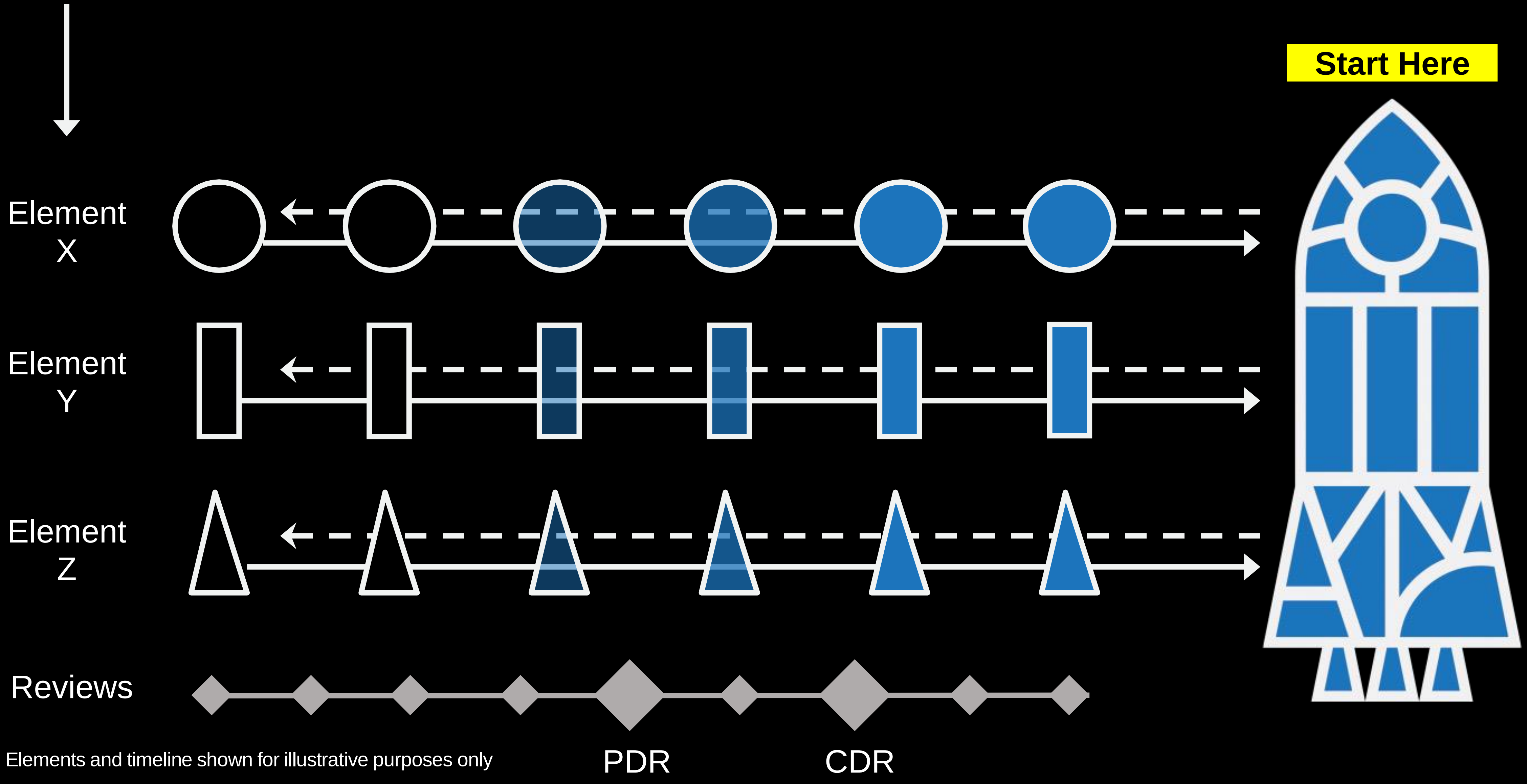
- 30+ year roller-coaster ride for Moon to Mars (M2M) development
- Widespread stress/anxiety in the wake of multiple shifts in approach
- Capability-based approach does not fully support a long-term strategy to Mars
  - Need objective-based / goal-based approach
- Must think strategically…

…with resilience/flexibility in mind…

…to better achieve unity of purpose

Execute from the Left

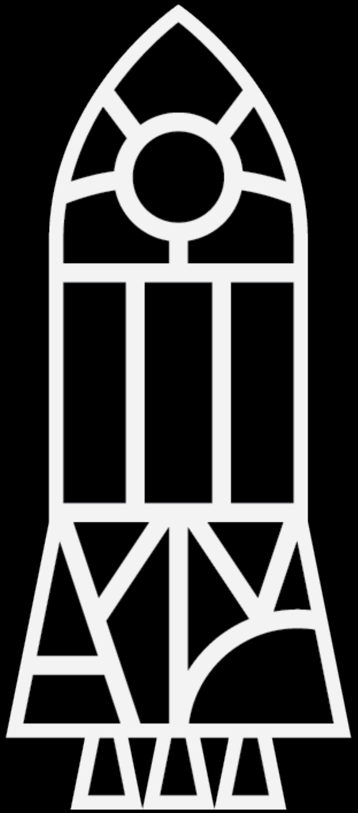
Architect from the Right



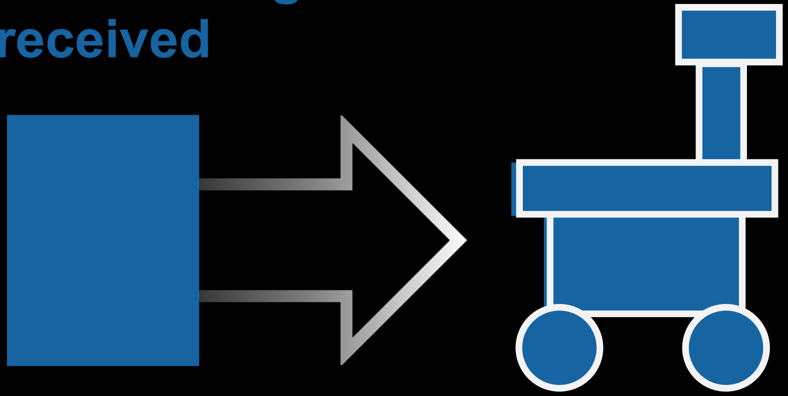
Elements and timeline shown for illustrative purposes only

Stick with the Plan

The M2M Plan



Limited funding received

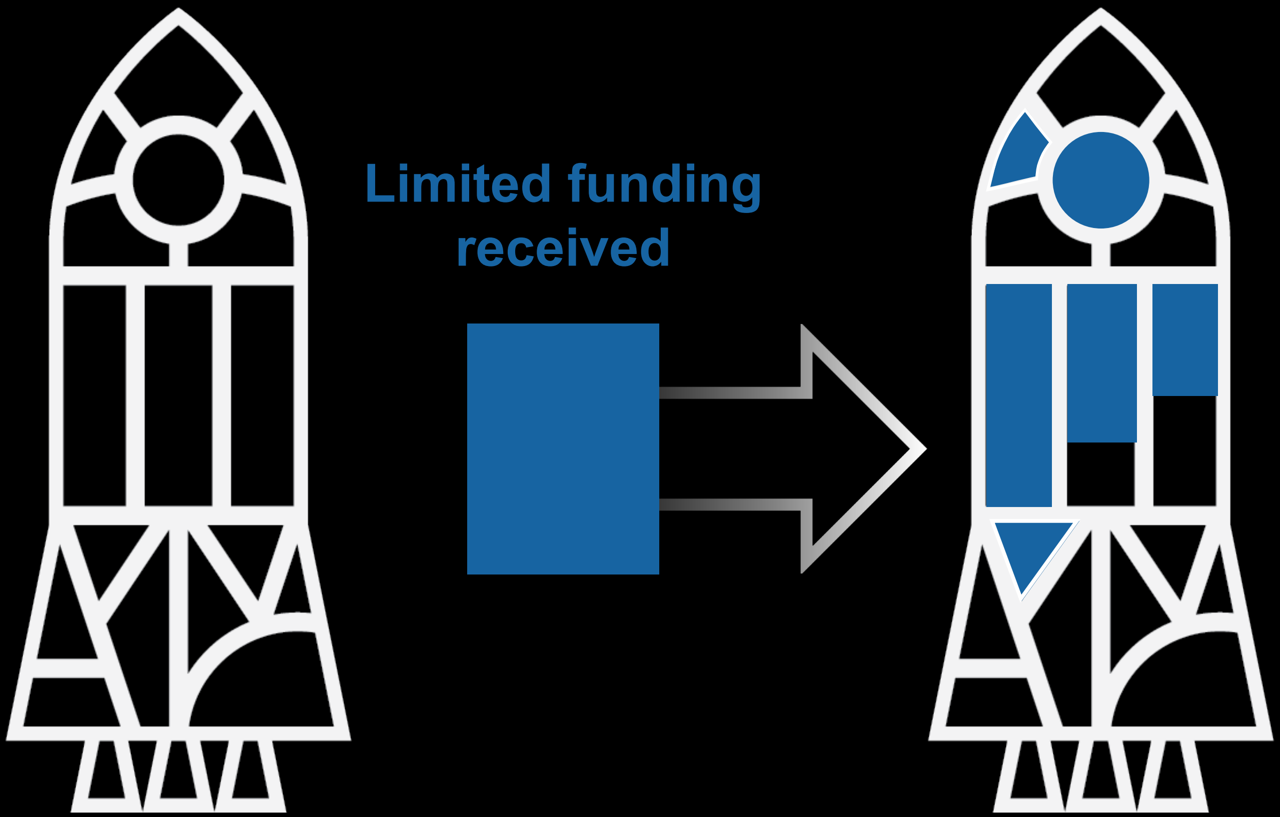


Alter the plan to match the funding

- Totally different goal
- Questionable technical rigor
- New baseline from which future cuts occur
- Lose pace on original goal

Stick with the Plan

The M2M Plan

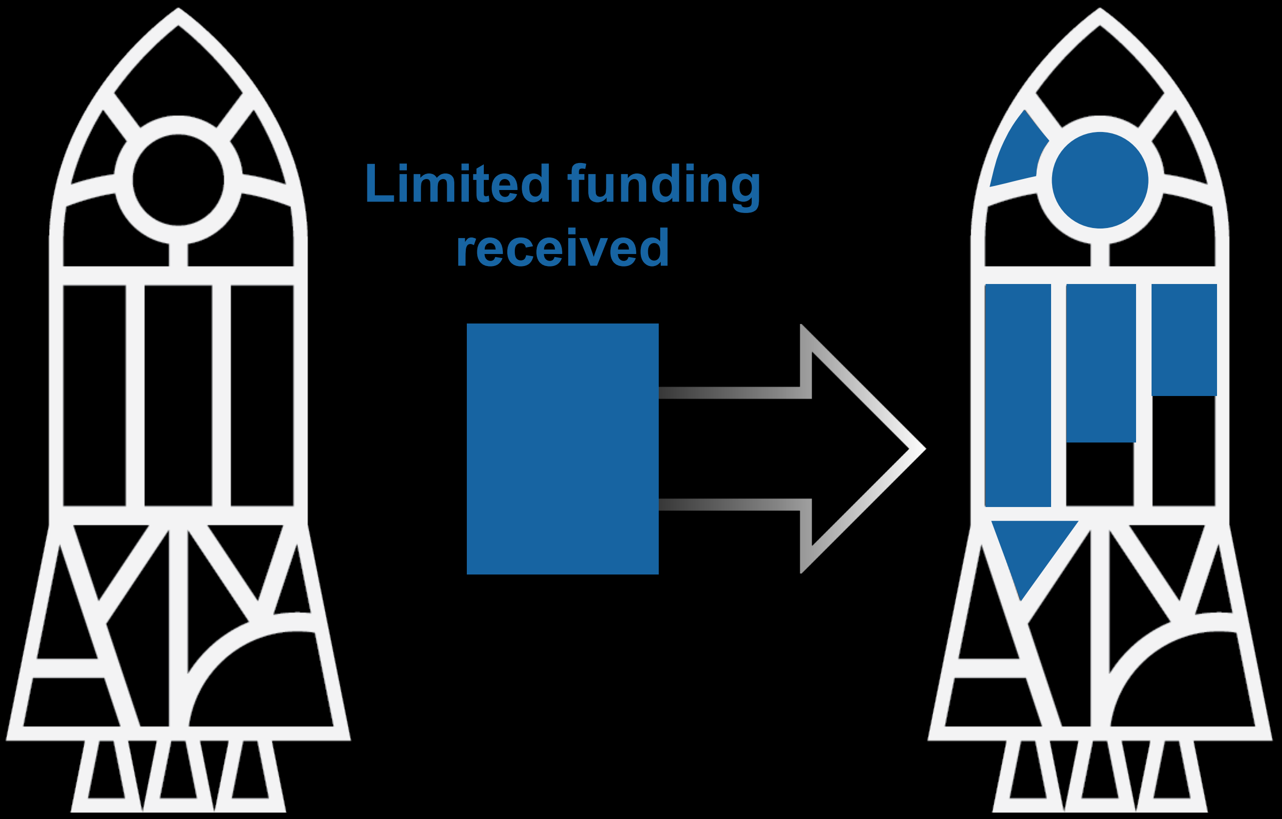


Stick with the plan, adjust to funding received

- Constancy of purpose
- Prioritize and prepare for more fruitful days
- Slow progress, but maintain technical credibility

Stick with the Plan…. almost

The M2M Plan



Attempts to "Stick with the plan" behind the scenes…

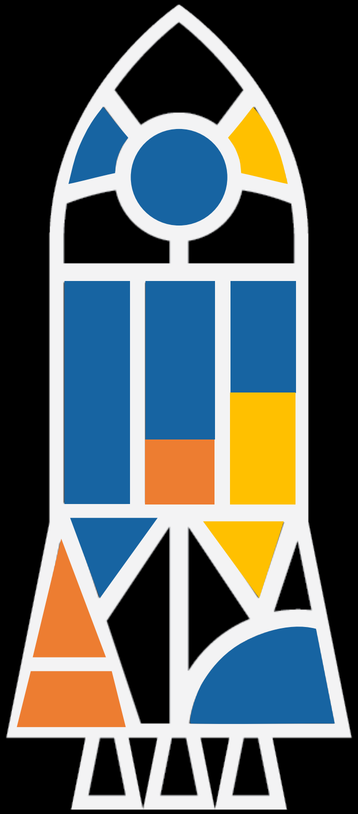
- Initially, prioritize and prepare for more fruitful days
- Decentralized efforts
- Over time lose clarity on overall plan

Stick with the Plan

Funded by NASA/ the Hill

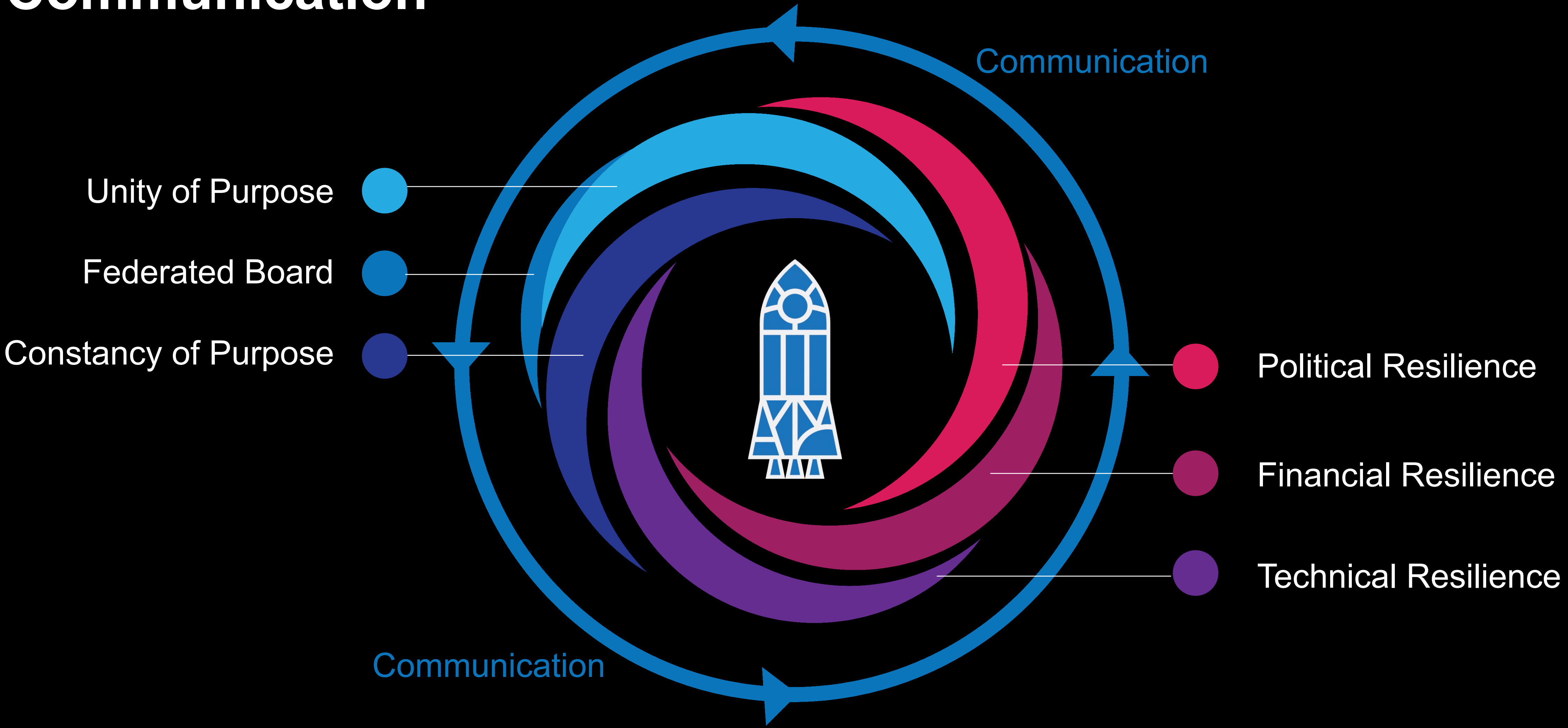
Industry

International



- Constancy of purpose
- Prioritize and prepare for more fruitful days
- Slow progress, but maintain technical credibility
- Consistent opportunity paths for International and Industry partners

Communication



Communication is the catalyst that ensures unity/constancy of purpose and resilience

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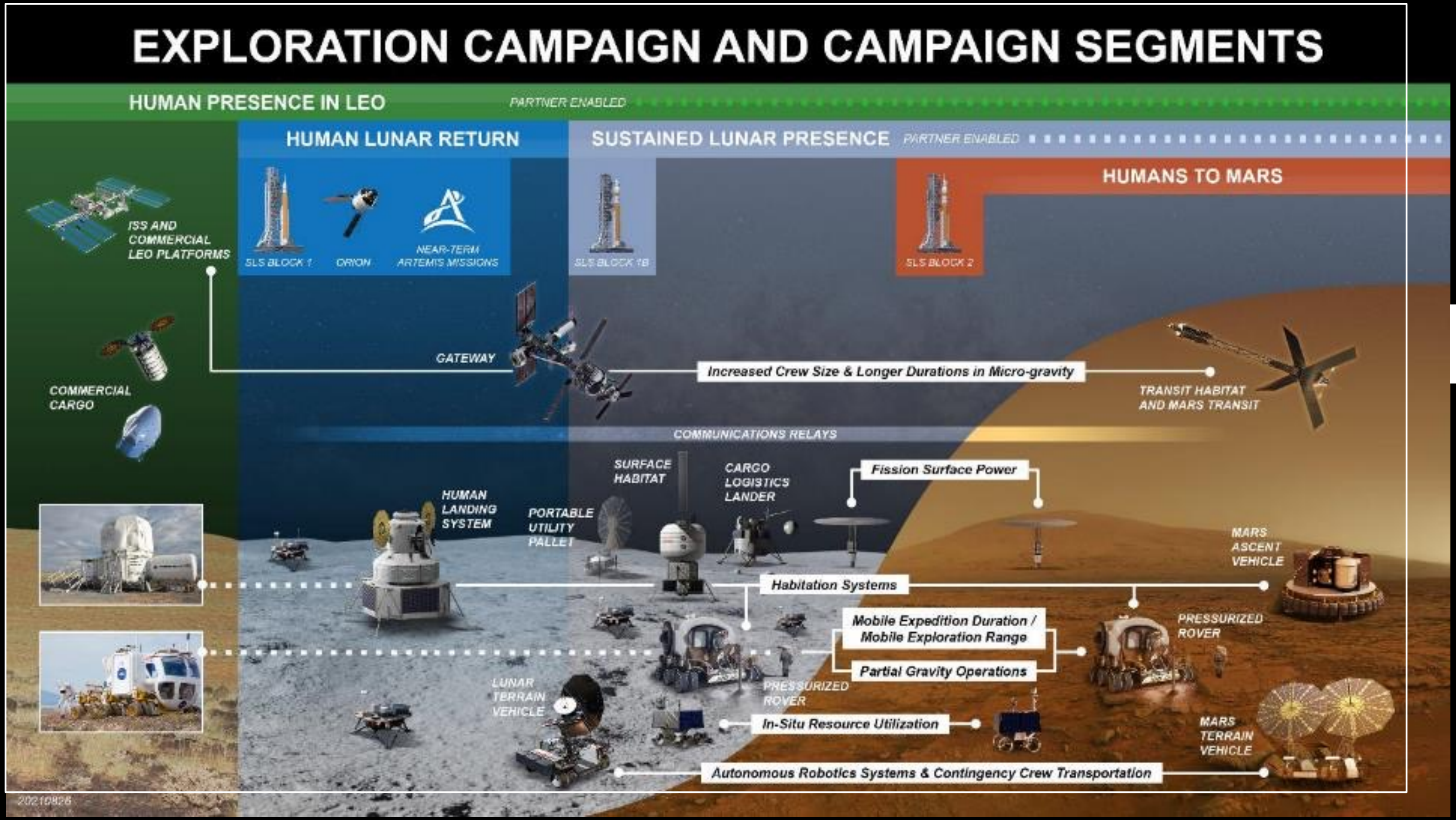
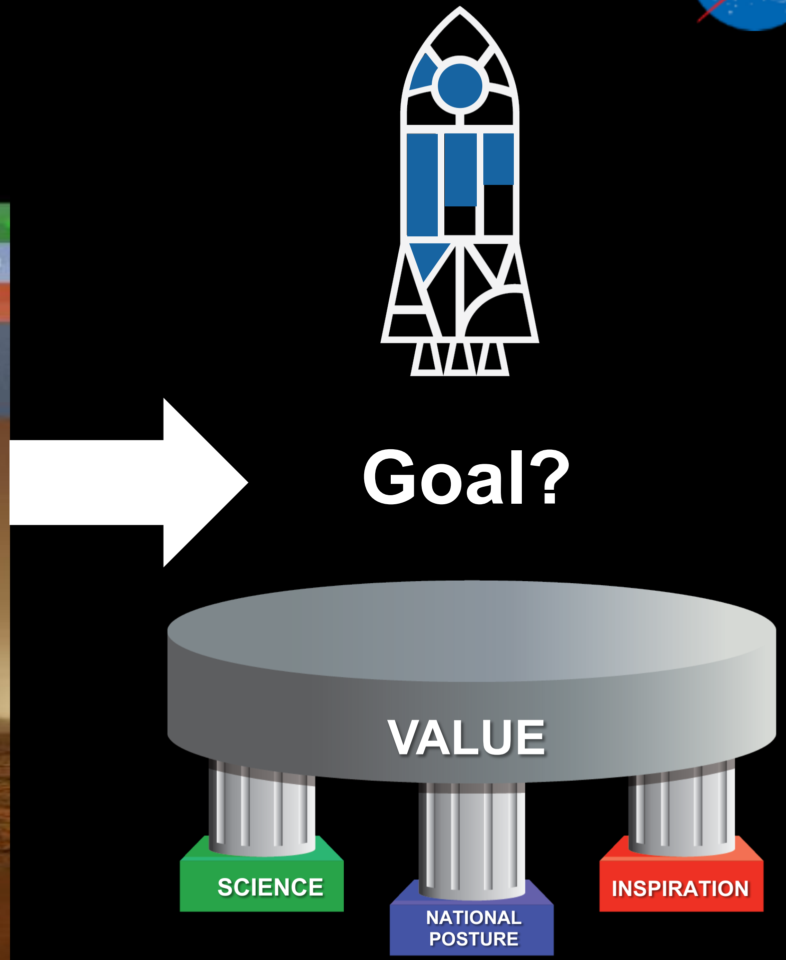
Current Campaign Description



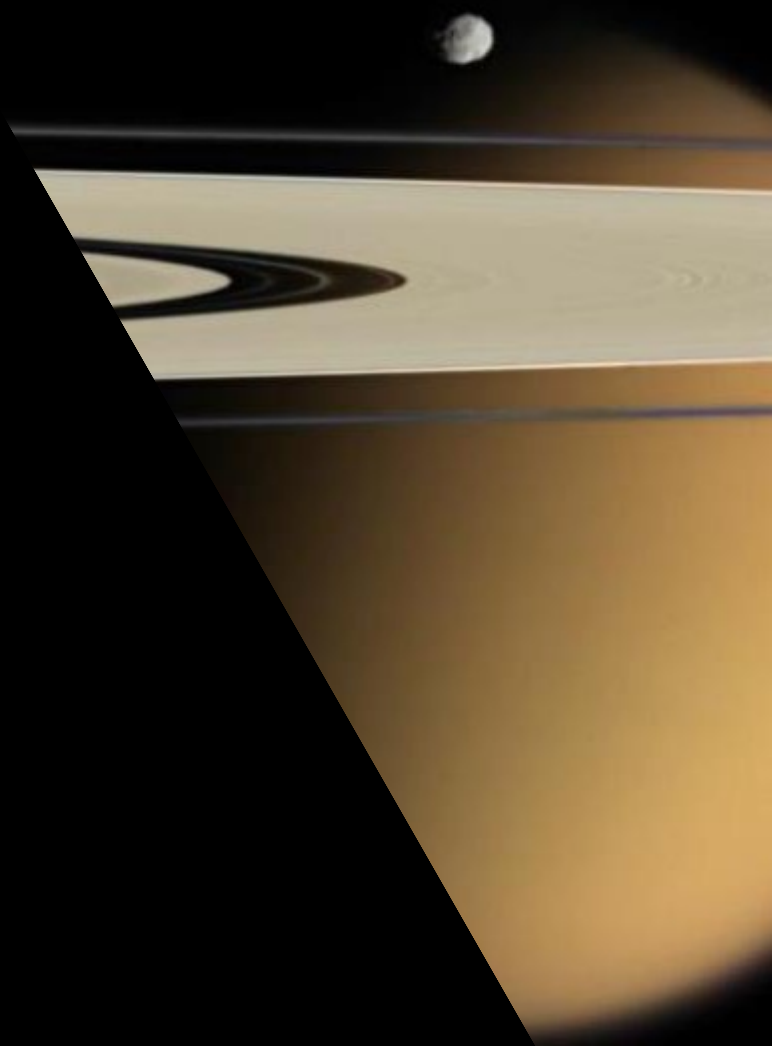


Capability focus: we’re generating a bunch of “things”– what is our goal?

A Goal-Based Approach

Create a blueprint for sustained human presence & exploration throughout the solar system

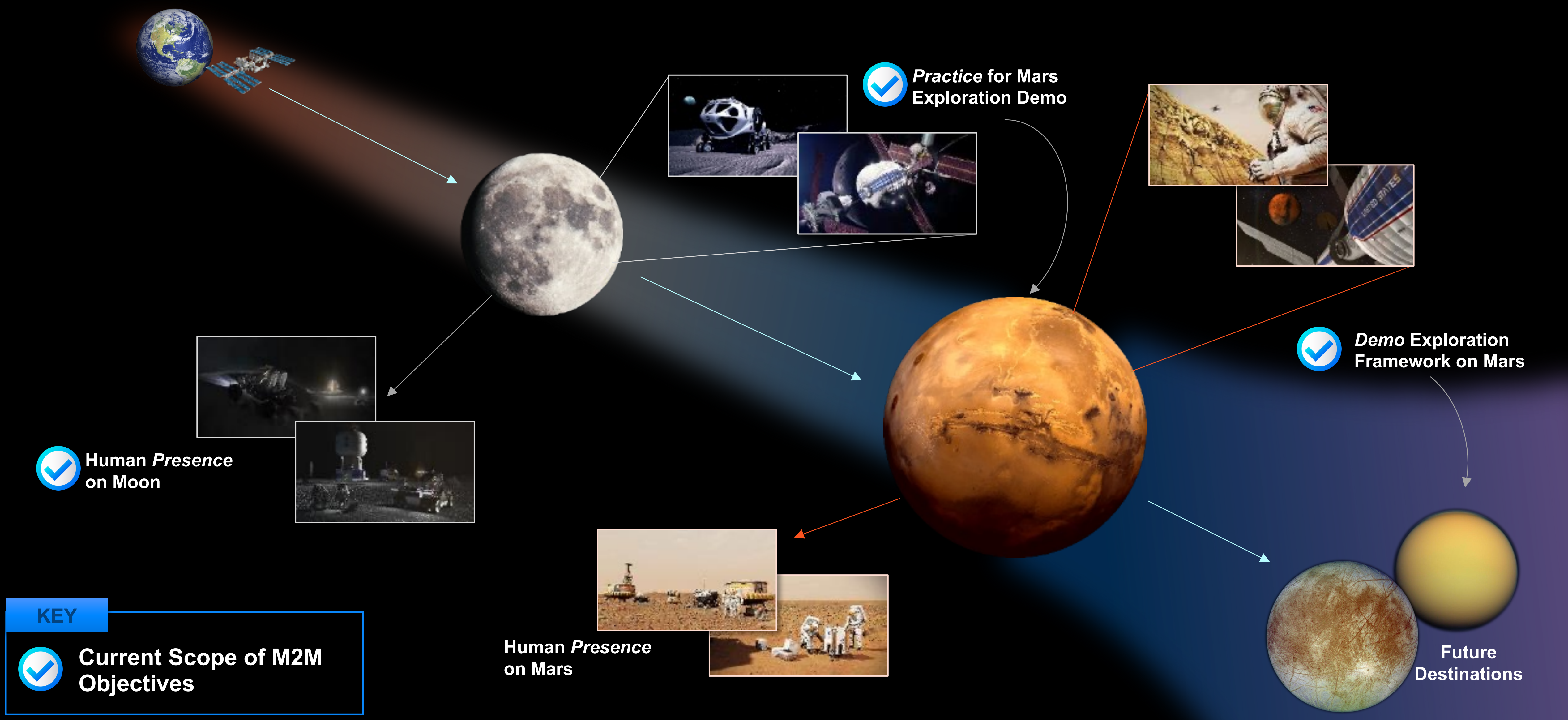
- What is our strategy towards that goal?
- Ex: we know we need to practice on the Moon
- Must flesh out details of an overall strategy against that over-arching goal



A goal-based approach asks, “What do we need to demonstrate and achieve to be ready to go to Mars?” NASA proposes looking through the following lenses:

Transportation and Habitation	Infrastructure
Operations	Science

Current Moon to Mars Scope



Architecting from the Right

Objectives Goals Areas/"Buckets"

TH-3

Develop systems to allow crew to live and operate safely on the lunar surface and lunar orbit for extended periods of time with scalability to continuous presence to visit areas of interest for scientific research, conduct Mars analog activities, support industrial utilization, and conduct utilization activities.

ARMD

LI-3

Demonstrate autonomous construction, precision landing, surface transportation, industrial scale ISRU and Advanced Manufacturing capabilities in support of future continuous human lunar presence and a robust lunar economy.

Conduct human research and technology demonstrations on the surface of the Earth, low Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on system performance, reduce risk, and shorten the timeframe for system testing and readiness prior to the first human mission to Mars.

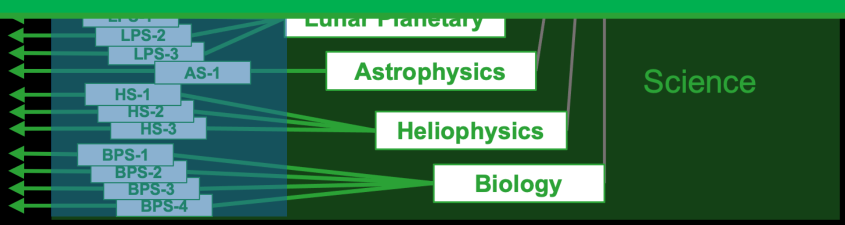
SMD requirements to ESDMD and exploration throughout the solar system

SOMD

STMD

ES-5

Demonstrate retrieval of frozen volatile deep core samples from permanently shadowed regions on the Moon.



Transportation and Habitation Objectives

Transportation and Habitation Goal: Develop and demonstrate an integrated system of systems to conduct a campaign of human missions to the Moon and Mars, living and working on the lunar and Martian surface, and a safe return to Earth.

- TH-1: Develop cislunar systems that crew can routinely operate to lunar orbit and lunar surface for extended durations.
- TH-2: Develop systems that can routinely deliver large surface elements to the lunar surface.
- TH-3: Develop systems to allow crew to live and operate safely on the lunar surface and lunar orbit for extended periods of time with scalability to continuous presence to visit areas of interest for scientific research, conduct Mars analog activities, support industrial utilization, and conduct utilization activities.
- TH-4: Develop a habitation system for crew in deep space for extended durations, enabling future missions to Mars.
- TH-5: Develop a transportation system that crew can routinely operate from the Earth-moon vicinity to Mars orbit and Martian surface.
- TH-6: Develop a transportation system that can deliver large surface elements from Earth to the Martian surface.
- TH-7: Develop systems for crew to live, operate, and explore on the Martian surface to address key questions with respect to science and resources.
- TH-8: Develop a system that monitors crew health and performance and provides medical care to the crew during long communication delays to Earth and in an environment that does not allow emergency evacuation nor terrestrial medical assistance.
- TH-9: Develop integrated human and robotic systems with inter-relationships that enable maximum science return from the lunar surface and from lunar orbit.
- TH-10: Develop integrated human and robotic systems with inter-relationships that enable maximum science return from the Mars surface and from Mars orbit.
- TH-11: Develop systems capable of returning large cargo mass from the lunar surface to the Earth, including the capabilities necessary to meet scientific sample return objectives.
- TH-12: Develop systems capable of returning large cargo mass from the Martian surface to the Earth, including the capabilities necessary to meet scientific sample return objectives.

Lunar and Martian Infrastructure Objectives

Lunar Infrastructure (LI) Goal: Create Global Lunar Utilization infrastructure where U.S. industry and international partners can maintain continuous robotic and human presence on the lunar surface for a robust lunar economy without NASA as the sole user, while accomplishing Mars testing and science objectives.

LI-1: Develop an incremental lunar power grid that is evolvable to support continuous human/robotic operation and is capable of scaling to global power utilization and industrial power levels.

LI-2: Develop Lunar surface, orbital, & Lunar to Earth communications, position, navigation and timing architecture capable of scaling to support long term science, exploration, and industrial needs.

LI-3: Demonstrate autonomous construction, precision landing, surface transportation, industrial scale ISRU and Advanced Manufacturing capabilities in support of future continuous human lunar presence and a robust lunar economy.

LI-4: Demonstrate technologies supporting cislunar orbital/surface depots, construction and manufacturing maximizing the use of in-situ materials, and support systems needed for continuous human/robotic presence.

Martian Infrastructure (MI) Goal: Create essential infrastructure to support initial human Mars demonstration.

MI-1: Develop Mars Surface Power sufficient for the initial human Mars demonstration mission.

MI-2: Develop Mars surface, orbital, & Mars to Earth communications to support the initial human Mars demonstration mission.

MI-3: Develop and demonstrate entry, descent, and landing (EDL) systems capable of delivering crew and large cargo to the Martian surface.

Operations Objectives

Operations Goal: Conduct human missions on the surface and around the Moon followed by missions to Mars. Using a gradual build-up approach, these missions will demonstrate technologies and operations to live and work on a planetary surface other than Earth, with a safe return to Earth at the completion of the missions.

OP-1: Conduct human research and technology demonstrations on the surface of the Earth, low Earth orbit platforms, cislunar platforms, and on the surface of the moon, to evaluate the effects of extended mission durations on system performance, reduce risk, and shorten the timeframe for system testing and readiness prior to the first human mission to Mars.

OP-2: Optimize operations, training and interaction between crew, the support team on Earth, orbital support and a Martian surface team considering communication delays, autonomy level, and time required for an early return to the Earth.

OP-3: Characterize accessible lunar resources, gather scientific research data, and analyze potential reserves to satisfy science and technology objectives and enable ISRU on successive missions.

OP-4: Establish command, control and coordination and processes that will support expanding human missions at the Moon and Mars.

OP-5: Operate surface mobility systems using extra-vehicular activity (EVA), suits, tools and vehicles.

OP-6: Evaluate, understand, and mitigate the impacts on crew health and performance of a long deep space orbital mission, followed by partial gravity surface operations on the Moon.

OP-7: Validate readiness of systems and operations to support crew health and performance on the first human mission to Mars.

OP-8: Demonstrate the capability to find, service, upgrade, or utilize instruments and equipment from robotic landers or previous human missions on the surface of the Moon and Mars.

OP-9: Demonstrate the capability of integrated robotic systems to support and augment the work of crewmembers on the lunar surface, and in orbit around the Moon.

OP-10: Demonstrate the capability to remotely operate robotic systems that are used to support crew members on the Lunar or Martian surface, from the Earth or from orbiting platforms.

OP-11: Demonstrate the capability to use commodities produced from planetary surface or in-space resources to reduce the mass required to be transported from Earth.

Science Objectives (1 of 2)

Exploration Science (ES) Goal: Conduct science on the Moon and in cislunar space, using integrated human and robotic methods and advanced techniques, to address high priority U.S. scientific questions about the Moon and to demonstrate methods for future science by astronauts beyond the Earth-Moon system.

ES-1: Conduct human field geology on the surface and select high priority sample specimens for return to Earth.

ES-2: Demonstrate advanced techniques and tools to enable Earth-based scientists to remotely guide astronaut surface activities.

ES-3: Enable in-situ research by delivering science instruments to the lunar surface at various locations and returning high priority samples to Earth.

ES-4: Survey sites, conduct in-situ measurements, and identify/stockpile samples for later astronaut evaluation or retrieval.

ES-5: Demonstrate retrieval of frozen volatile deep core samples from permanently shadowed regions on the Moon.

ES-6: Establish methods and systems to allow a large number of science instruments to conduct planetwide long-term measurements.

ES-7: Establish a scientific laboratory at the lunar South Pole to conduct high value lunar surface science.

ES-8: Utilize Mars Sample Return (MSR) mission results to optimize human-led science sampling campaigns on Mars, sample return to Earth and characterize landing sites.

Lunar/Planetary Science (LPS) Goal: Address those high priority planetary science questions which are best accomplished by on-site human explorers on the Moon and Mars, aided by robotic systems.

LPS-1: Conduct studies of planetary processes (e.g., impact, volcanism, tectonism, regolith formation, and atmosphere dynamics) to understand the dynamics and chronology of planet evolution.

LPS-2: Collect fundamental data to understand the origin, distribution, abundance, composition, transport, and sequestration of volatiles throughout the solar system.

LPS-3: Conduct analyses to constrain the chronology and dynamics of early Solar System history, including planetary differentiation, early bombardment history, and the formation of the Earth-Moon system.

LPS-4: Collect samples over a long traverse/duration in the South Pole Aitken Basin and deliver the samples to astronauts for return to Earth.

Science Objectives (2 of 2)

Heliophysics Science (HS) Goal: Address those high priority heliophysics science and space weather questions which are best accomplished using a combination of human explorers and robotic systems on the Moon and in cislunar space.

HS-1: Understand space weather phenomena to enable improved prediction of the dynamic space environment for deep space exploration.

HS-2: Remotely observe the Sun and Geospace and conduct in-situ measurements in the deep magnetotail and pristine solar wind, to understand the dynamics of the connected Sun-Earth system.

HS-3: Discover and characterize fundamental plasma processes including dust-plasma interactions, using the cis-lunar environment as a laboratory.

Biological and Physical Science (BPS) Goal: Understand fundamental biological effects when organisms are present in fractional-gravity and deep-space environments, to gain new scientific understanding and information to guide system development.

BPS-1: Understand the fundamental biological effects of short and long duration exposure to the lunar environment on human physiology and disease.

BPS-2: Understand the fundamental biological effects of short and long duration exposure to the lunar environment on plants used to provide crew nutrition/behavioral health.

BPS-3: Understand the fundamental biological effects of short and long duration exposure to the lunar environment on the survival and adaptation of microbes associated with the crew, plants, and the built environment.

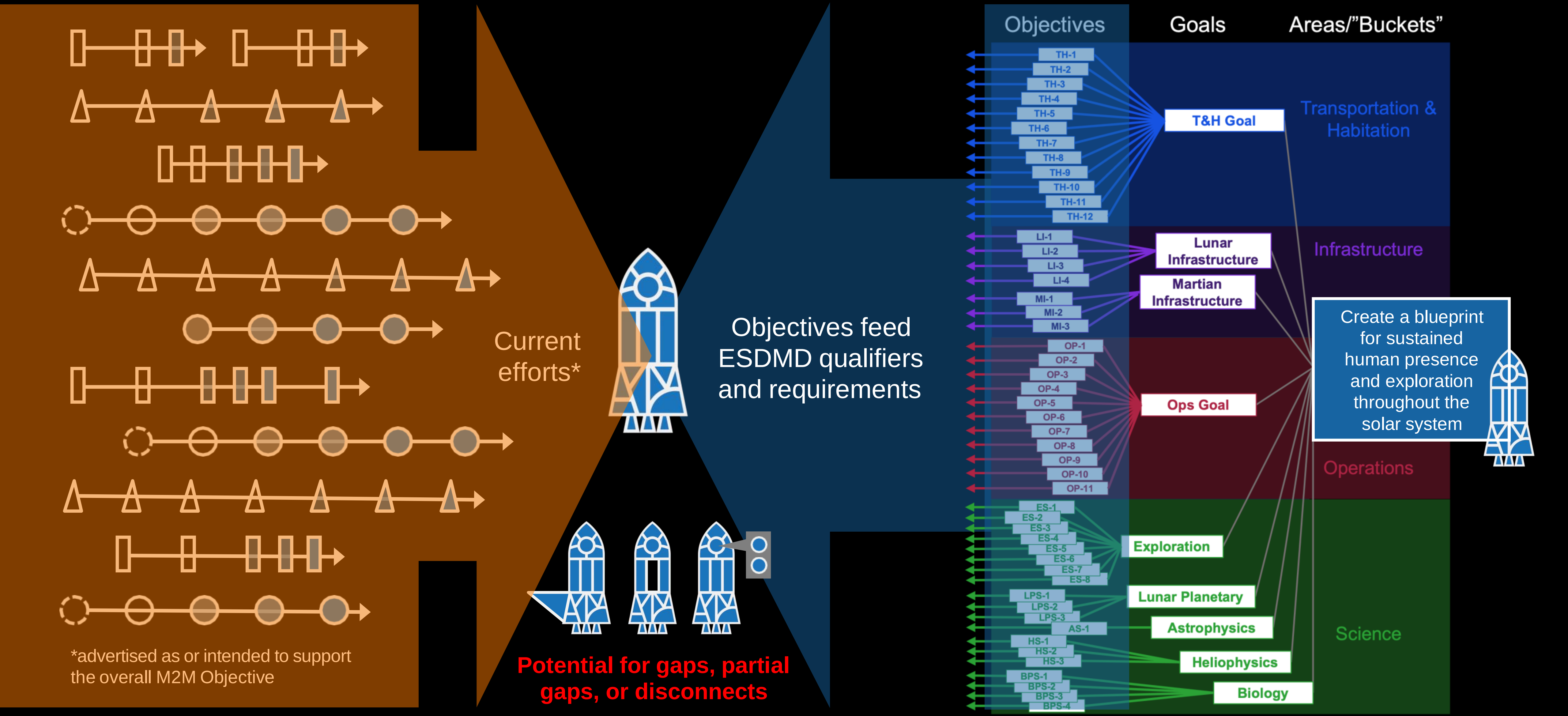
BPS-4: Understand transient or permanent physiological changes on several generations of organisms.

Astrophysics Science (AS) Goal*:* Preserve the far side of the Moon as a “radio-free zone” for future radio astronomy experiments.

AS-1: Monitor the radiofrequency environment on the lunar far side to enable future far side radioastronomy activities.

Building the Bridge

“Architecting from the Right” meets “On-going Developments”



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- **Gap Analysis & Way Ahead**
- STMD’s role

Federated Board Update

New Charter and Latest Developments

The Federated Board (FB) seeks to drive consensus, promote efficient conflict resolution, help interpret strategic guidance and expectations from Agency leadership, and provide advice to Mission Directorate/Agency leadership, including governance councils. It is not a decision-making body.

Recent scope revisions emphasized **structured vetting and **advisory** functions to the existing FB. However, architecture ownership resides in the MD.*

FEDERATED BOARD

Executive Secretariat

Chair

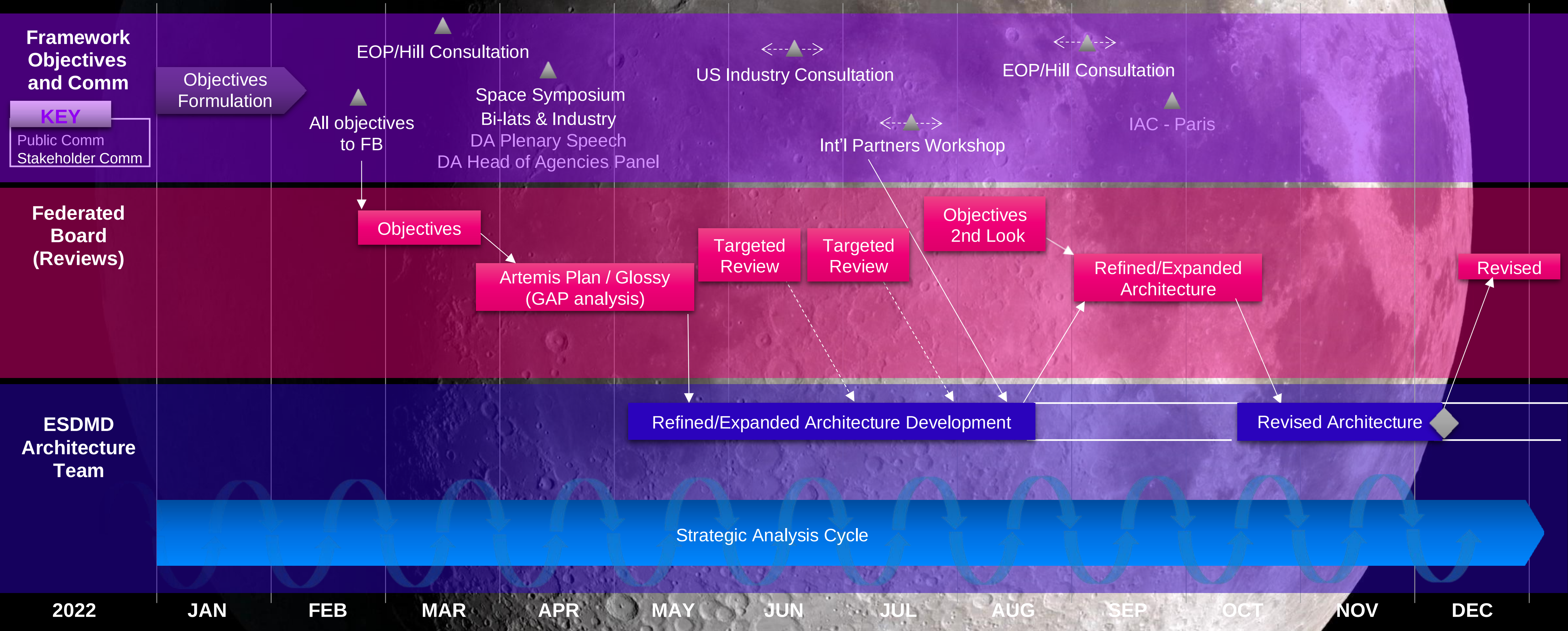
ARMD | **SOMD** | **ESDMD** | **A-Suite DSA** | **SMD** | **STMD** | **Auxiliary Members: As Required**

CORE FUNCTIONS

- Coordinate
- Review
- Advise
- Advocate

Ensures Agency priorities and general architectural direction are tightly/efficiently integrated for Artemis/M2M and other activities that require coordination across the Mission Directorates (MDs)

Framework Objectives and Moon to Mars Architecture Timeline



Bridge Gap Analysis

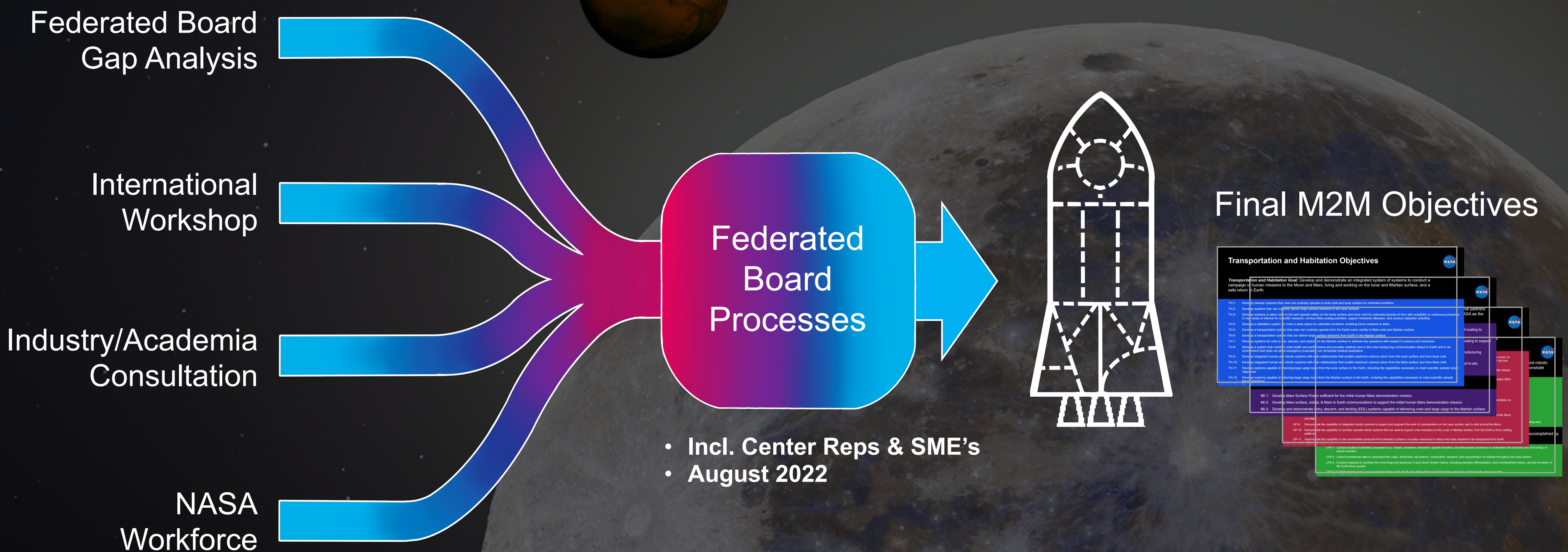
- **Began April ’22**
  - Mapped advertised M2M efforts to objectives (broad first look)
  - Identify gaps, disconnects, disagreements

- **3 Rounds**
  - Round 1: Mission Directorate self-assessment
  - Round 2: Federated Board (FB) members’ cross-assessment
  - Round 3: Federated Board-sponsored SME deep-dives

- **By end of Round 2, Federated Board had identified:**
  - 12 objectives gaps (including edits and new objectives in release)
  - 19 architectural/technical gaps (including 5 major gaps)
  - 23 watch items

- **Round 3 deep-dives planned completion by early August**

The Summer Scrub



- Incl. Center Reps & SME's
- August 2022

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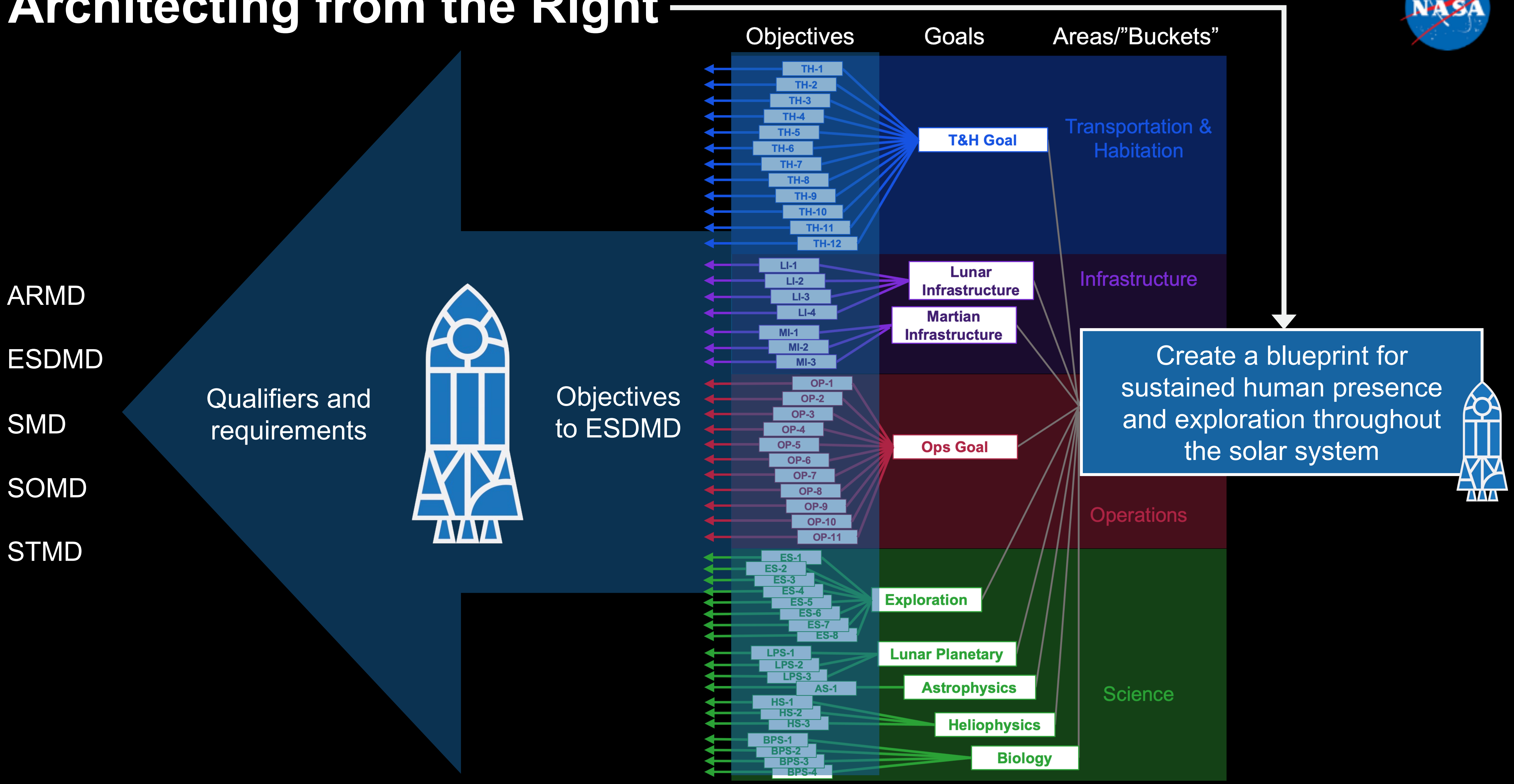
- **STMD's role**

BACK UP

Architecting from the Right



Glossary of Terms

Architecture: A set of functional capabilities, their translation into elements, their interrelations and operations. The architecture enables the implementation of various mission scenarios that achieve a set of given goals and objectives.

Campaign: A series of interrelated missions that together achieve agency goals and objectives.

Continuous presence: Steady cadence of human/robotic missions in subject orbit/surface with the desired endpoint of 365/24/7 operations.

Demonstrate: NASA deploys an initial capability to enable system maturation and future industry growth in alignment with architecture objectives.

Develop: NASA designs, builds, and deploys a system, ready to be operated by the user, to fully meet architectural objectives

Explore: Excursion-based surface expeditions focused on science and technology tasks.

Global: Infrastructure and capabilities that support human and robotic operations and utilization across the subject planetary surface.

Incremental: Building compounding operational capabilities within the constraints of schedule, cost, risk, and access.

Glossary of Terms

Live: The ability to conduct activities beyond tasks on a schedule. Engage in hobbies, maintain contact with friends and family and maintain healthy work-life balance.

Mission: A major activity required to accomplish an Agency goal or to effectively pursue a scientific, technological, or engineering opportunity directly related to an Agency goal. Mission needs are independent of any particular system or technological solution.

Mobility: Powered surface travel that extends the exploration range beyond what is possible for astronauts to cover on foot. Spans robotic and crewed systems, and can be accomplished on and above the surface.

Routine: Recurring subject operations performed as part of a regular procedure rather than for a unique reason.

Scalability: Initial systems designed such that minimal recurring DDT&E is needed to increase the scale of a design to meet end state requirements.

Utilization: Use of the platform, campaign and/or mission to conduct science, research, test and evaluation, public outreach education, and industrialization of the subject body.

Validate: Confirming that a system satisfies its intended use in the intended environment (Did we build the right system?).

Overarching Objectives Principles

INHERENT ACROSS ALL OBJECTIVES

International Partnerships: partner with international community to promote resilience and achieve common goals and objectives.

Industry Collaboration: collaborate with commercial partners to create most effective solutions and achieve common goal and objectives.

Return Crew Safely: return crews to Earth in a safe manner at the conclusion of missions, or in the event crew health requires an earlier-than-planned return, while minimizing impacts to life expectancy.

Maximize Crew Time: maximize crew time for science and engineering activities across all systems and operations.

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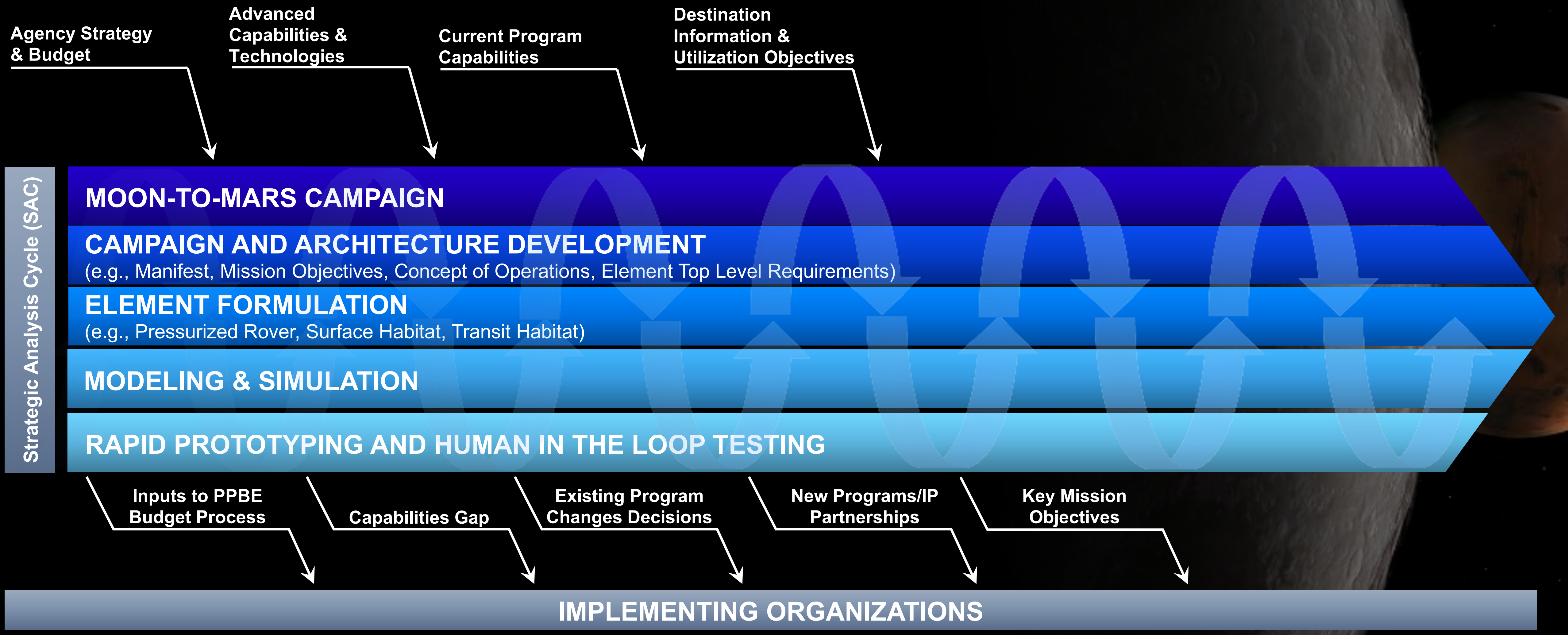
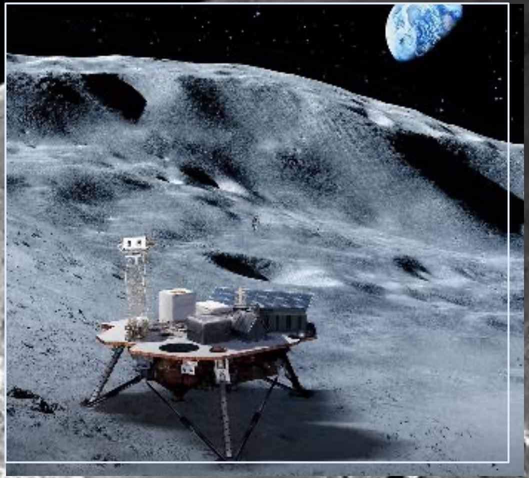
- **Architecture Today & Planning**
- Gap Analysis & Way Ahead

Moon to Mars Architecture and Element Development and Refinement



Human Exploration Focus



SCIENCE

Connects all elements

Enables architecture
Ex: In-situ Resource Utilization

Incorporation of Decadal Level Science

ANNUAL LUNAR SURFACE MISSIONS

2025-2031
2 Crew | 6.5-14 days

2031+
4 Crew | 30 days

MARS

Analogs
Space Station | Moon

Robotic Sample Return
Volatiles

EXPANDING PARTNERSHIPS

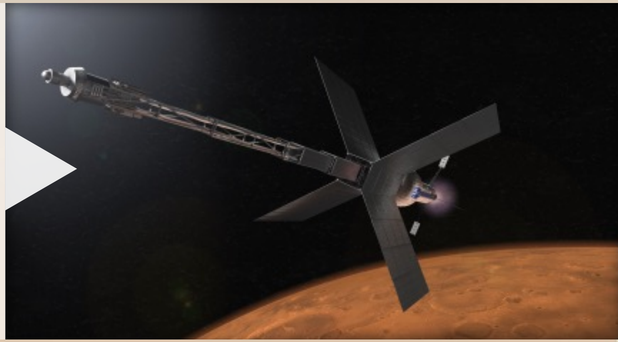
International
Existing and New Partners

Industry
Economic Development

Other Government
Agency Partners (DOE, NSF, NIH)

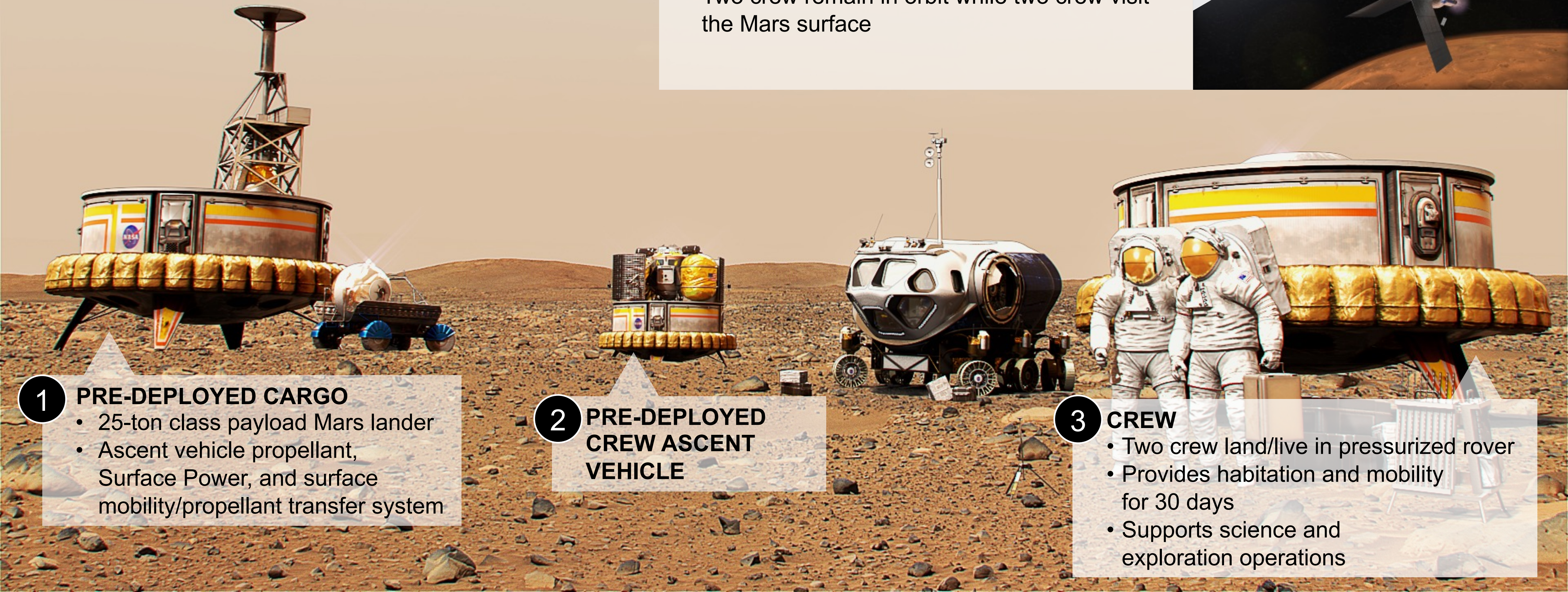
First Conceptual Mars Mission

Reference architecture for *analysis purposes only.*



TRANSIT HABITAT AND HYBRID PROPULSION STAGE

- Supports four crew on the long mission to Mars
- Two crew remain in orbit while two crew visit the Mars surface



1 PRE-DEPLOYED CARGO

- 25-ton class payload Mars lander
- Ascent vehicle propellant, Surface Power, and surface mobility/propellant transfer system

2 PRE-DEPLOYED CREW ASCENT VEHICLE

3 CREW

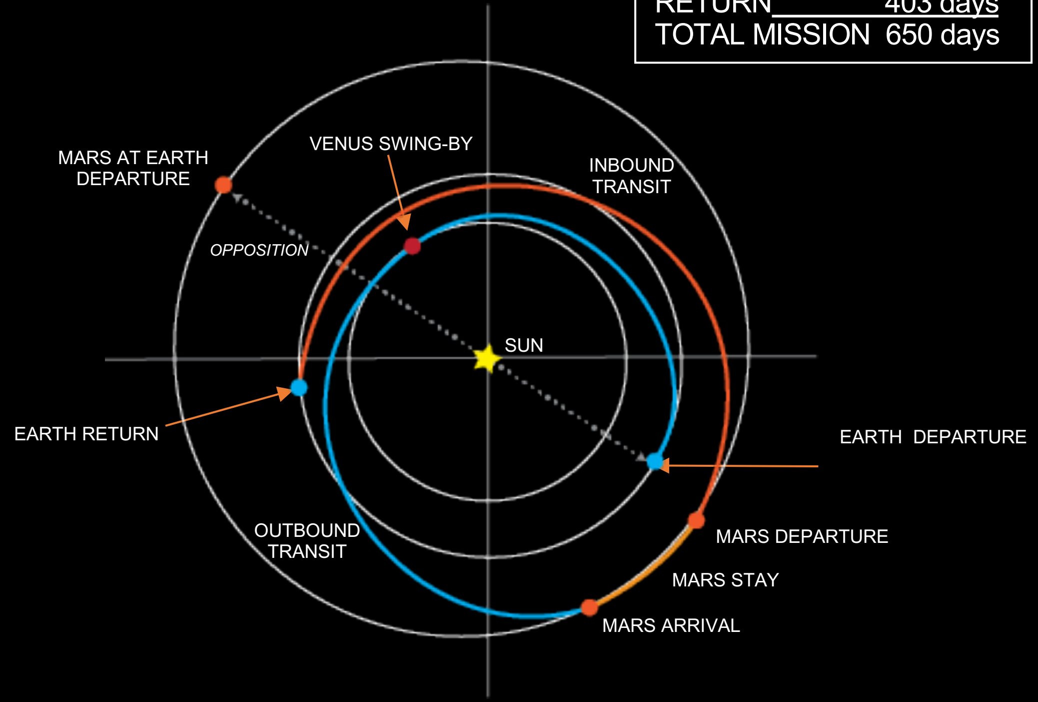
- Two crew land/live in pressurized rover
- Provides habitation and mobility for 30 days
- Supports science and exploration operations

Mars Trajectory Design Reference Architecture

Short-Stay Missions

Variations of missions with short Mars surface stays and may include Venus swing-by

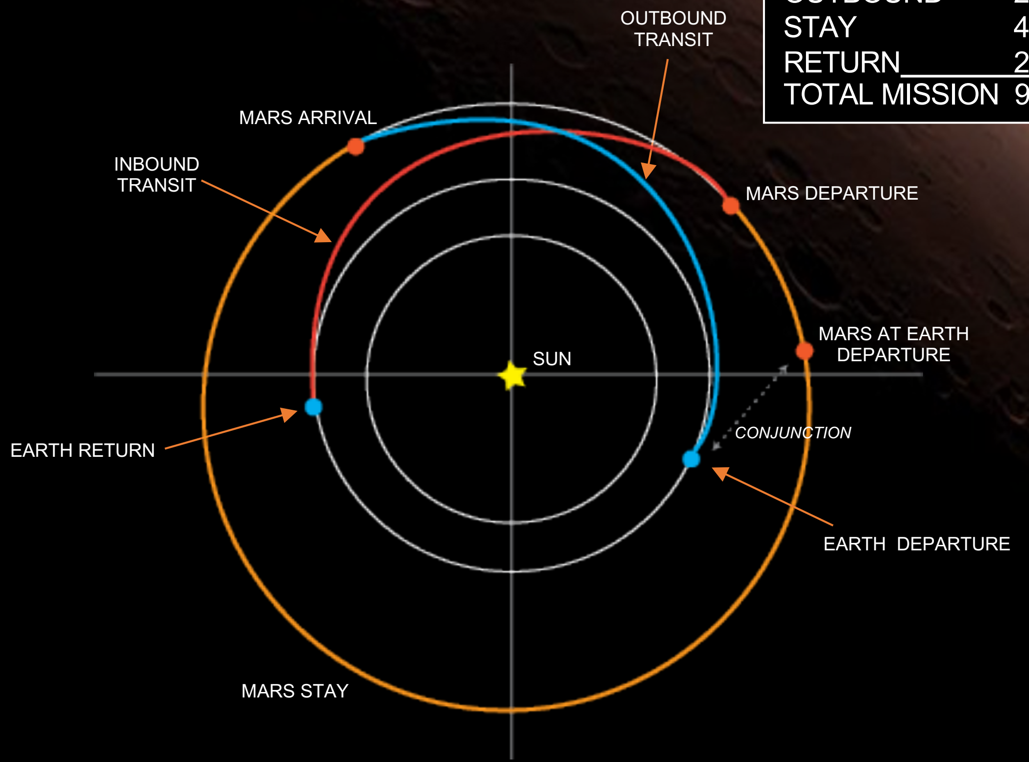
MISSION TIMES	
OUTBOUND	217 days
STAY	30 days
RETURN	403 days
TOTAL MISSION	650 days



Long-Stay Missions

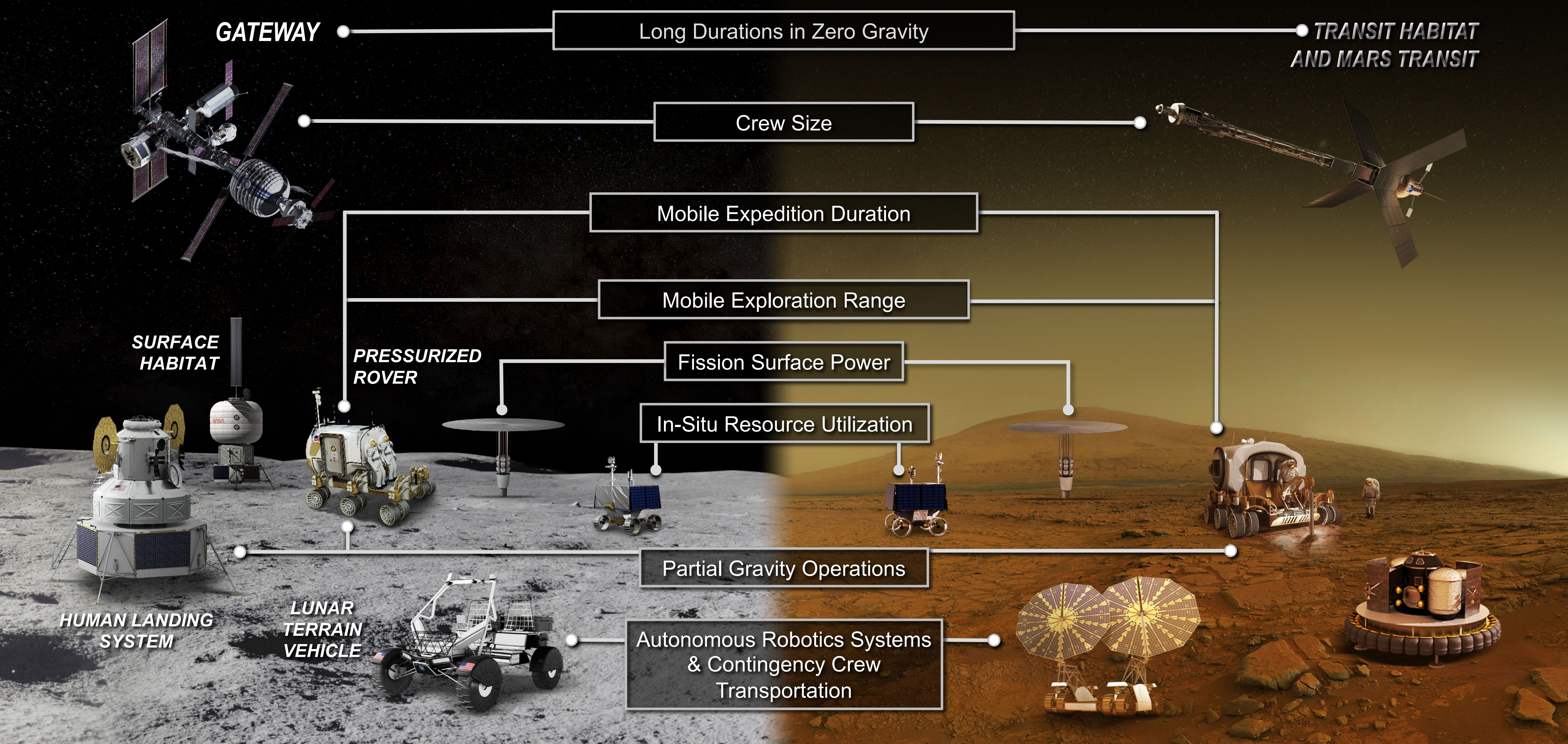
Variations about the minimum energy mission

MISSION TIMES	
OUTBOUND	210 days
STAY	496 days
RETURN	210 days
TOTAL MISSION	916 days

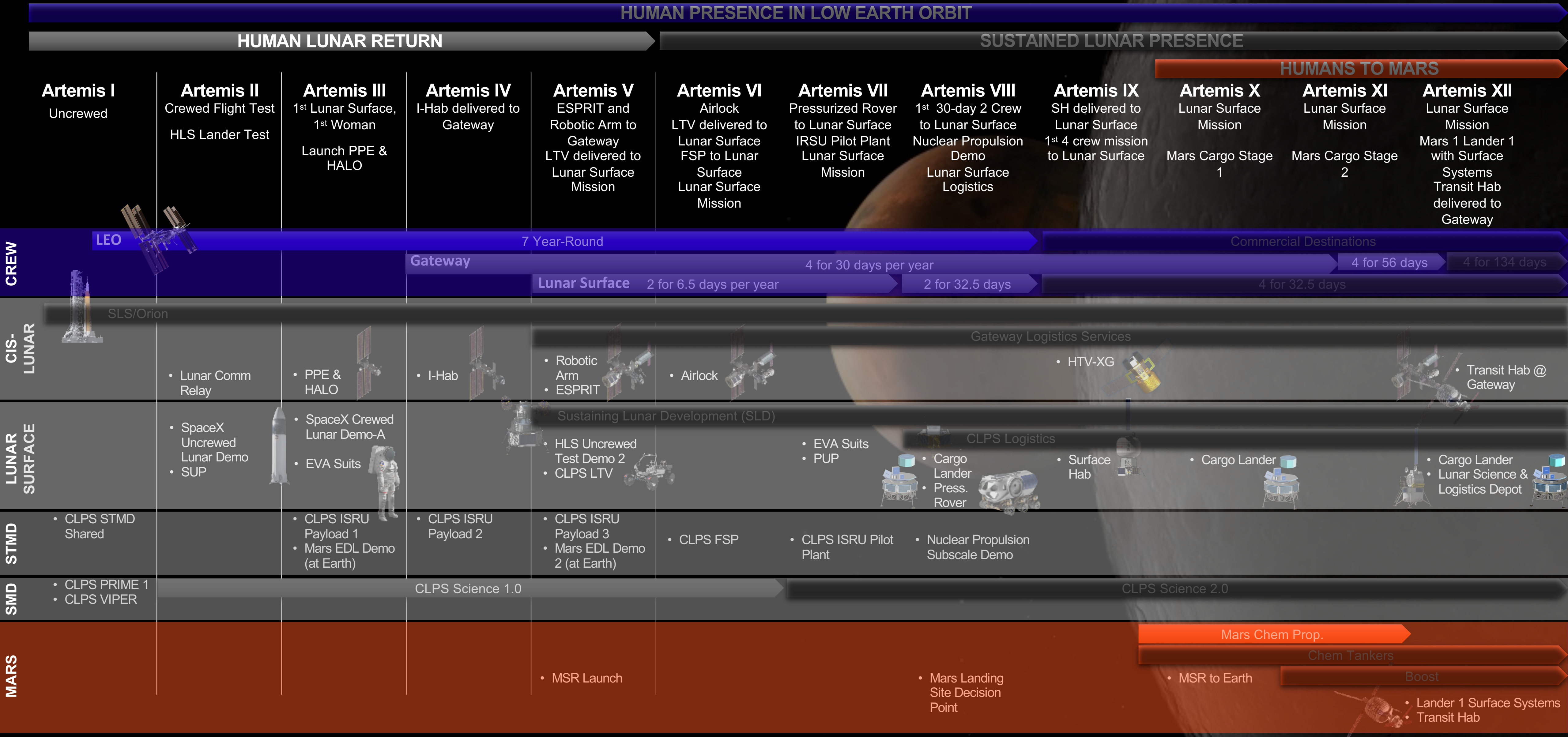


Moon to Mars Exploration Strategy

Operations on and around the Moon will help prepare for the first human mission to Mars



Strategic Analysis Cycle Representative



Moon to Mars Architecture Work

1. Integrate Objectives and Perform Gap Analysis
2. Develop Architecture Strategy
3. Integrate with Agency Stakeholders
4. Broaden International and Industry Engagement
5. Mature Architecture Options
6. Formulate Future Architecture Elements
7. Evaluate on Annual Cadence

Updates to the Architecture Process

Organization
- As part of the new ESDMD, the architecture office has established its internal structure

Decadal
- With a science focus, we will work with SMD on responses to and implementation on portions of decadal

New International Elements
- ASI – Signed study agreement for pressurized element(s)
- Japan – Continued focus on Pressurized Rover
- ESA – Lunar Surface elements and surface science

Landing Sites
- Continuing to refine landing site list to refine mission planning and element development for Artemis III

Architecture Concept Review
- Closeout of the objectives integration effort and gap analysis will be an NASA Internal Architecture Concept Review with results shared externally

White Papers
- NASA Deputy Administrator has asked ESDMD to deliver a series of short white papers on various aspects of the architecture. Those will begin after the completion of the ACR.

Procurements
- Awarded suits; Sustainable Lander in process; Future elements (e.g. LTV in work)

Moon to Mars Architecture Development

DAA: Catherine Koerner

- **INTERNATIONAL PARTNERSHIPS STRATEGY**
  - **IP**
    - Develop partnership opportunities
    - Represent architecture in international forums
- **STRATEGY AND ARCHITECTURES**
  - **STRATEGIC ANALYSIS**
    - Campaign development
    - Architecture dev and assessment
    - Assess requirements against Architecture
    - Modeling & Simulation
    - Human-in-the-Loop Testing